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CARDIAC ARRHYTHMIAS OCCURRING DURING ACCELERATION

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Cardiac Arrhythmias Occurring During Acceleration

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Forty-two pilots were exposed to $+G_x$ and $+G_z$ acceleration in a variety of profiles and the incidence of arrhythmias investigated.

$+G_z$ acceleration did not increase the incidence of arrhythmias. $+G_x$ acceleration increased the incidence of arrhythmias and this increase seemed related to both the degree and duration of acceleration.

Premature contractions, with and without aberrant conduction, from both the atria and ventricles were noted. One subject had paroxysmal atrial tachycardia with $+G_x$ acceleration.

Possible causal mechanisms are discussed.

PRIOR TO THE ADVENT of space flight, operational exposure to acceleration was confined to the $+G_z$ vector except in special circumstances such as outside loops ($-G_z$), catapult take-offs and JATO boost ($+G_x$), or barrier arrest landings ($-G_x$). These exceptional G vectors were usually of short duration and the magnitude of their physiologic effects produced no opertional constraints and, as a result, were investigated little.

The prolonged and frequently great accelerations inherent in attaining orbital velocities and atmospheric re-entry resulted in an early decision to utilize the recumbent, leg raised, position in rocket boosted flights because of man's greater tolerance to $+G_x$ acceleration. The $+G_x$ vector results in impaired respiratory function as a limiting factor and this has focused major attention on this system.

Cardiac arrhythmias have been reported with both $+G_x$ and $+G_z$ acceleration, usually as an ancillary finding in the course of other studies, while other investigators have commented on their absence.

The USAF School of Aerospace Medicine is called on to provide indoctrination in $+G_x$ and $+G_z$ acceleration for the class members of the USAF Aerospace Research Pilot School at Edwards AFB, California. These pilots are pre-selected on the basis of pilot proficiency and their flying record, and usually have an engineering or other scientific background. They are a population which, in age, experience, and competence, is roughly similar to the astronaut population and, indeed, the latter group, for the most part, is selected from the graduates of the Aerospace Research Pilot Course. Other special evaluations of pilots with records of long experience and superior performance are also carried out with the USAF SAM human centrifuge.

A thorough review of our acceleration records for these groups during the past year revealed a surprisingly large number of arrhythmias which were acceleration related and the results of this review are presented here.

METHODS

The great majority of the pilots fitting the above criteria, exposed to acceleration at the USAF SAM human centrifuge facility from April 1964 to April 1965, are covered in this report and fall into three groups.

Group I—This group, the largest, was composed of Aerospace Research Pilot Course members from Edwards AFB, California. Thirty such pilots received acceleration indoctrination at SAM during the above period and of these 30, the records of 26 were available, the other records having been given to the subject himself or destroyed. Figures 1 and 2 show the five series of acceleration profiles to which each man of this group was exposed. One to several days separated series. Series #1 can be seen to consist of a short 7 G peak, then a longer 7 G plateau and a 10 G plateau. Series #2 was a 12 G plateau. Series #3 was a projected G-time profile of a Gemini mission, boost, and re-entry, without of course, a weightless period. Series #4 was a $+G_z$ exposure with rapid onset runs and a gradual onset run, both to blackout with the rapid onset runs beginning at 3.0 G and increasing by 0.2 G increments on each succeeding run until blackout was reached. Series #5, like numbers 1, 2, and 3, was a $+G_x$ vector but to a peak of 15 G.

Group II—This group consisted of candidates for the Air Force's MOL (Manned Orbiting Laboratory) Program. There were 15 subjects in this group and records were available on 14 of the 15. All were graduates of the Aerospace Research Pilot School mentioned previously. These men were exposed on one day to the profile shown in Figure 3 consisting of boost peaks to 3.0, 4.2, and 2.4 G's followed by a 10.5 G re-entry profile and, after a short rest at 1 G, to a 15 G re-entry type profile. All were $+G_x$ exposures.

Group III—This was a group of eight pilots being evaluated for a special project, and the records of all eight were available. The profiles are shown in Figure 3. One day consisted of exposure to a short 7 $+G_x$ peak,

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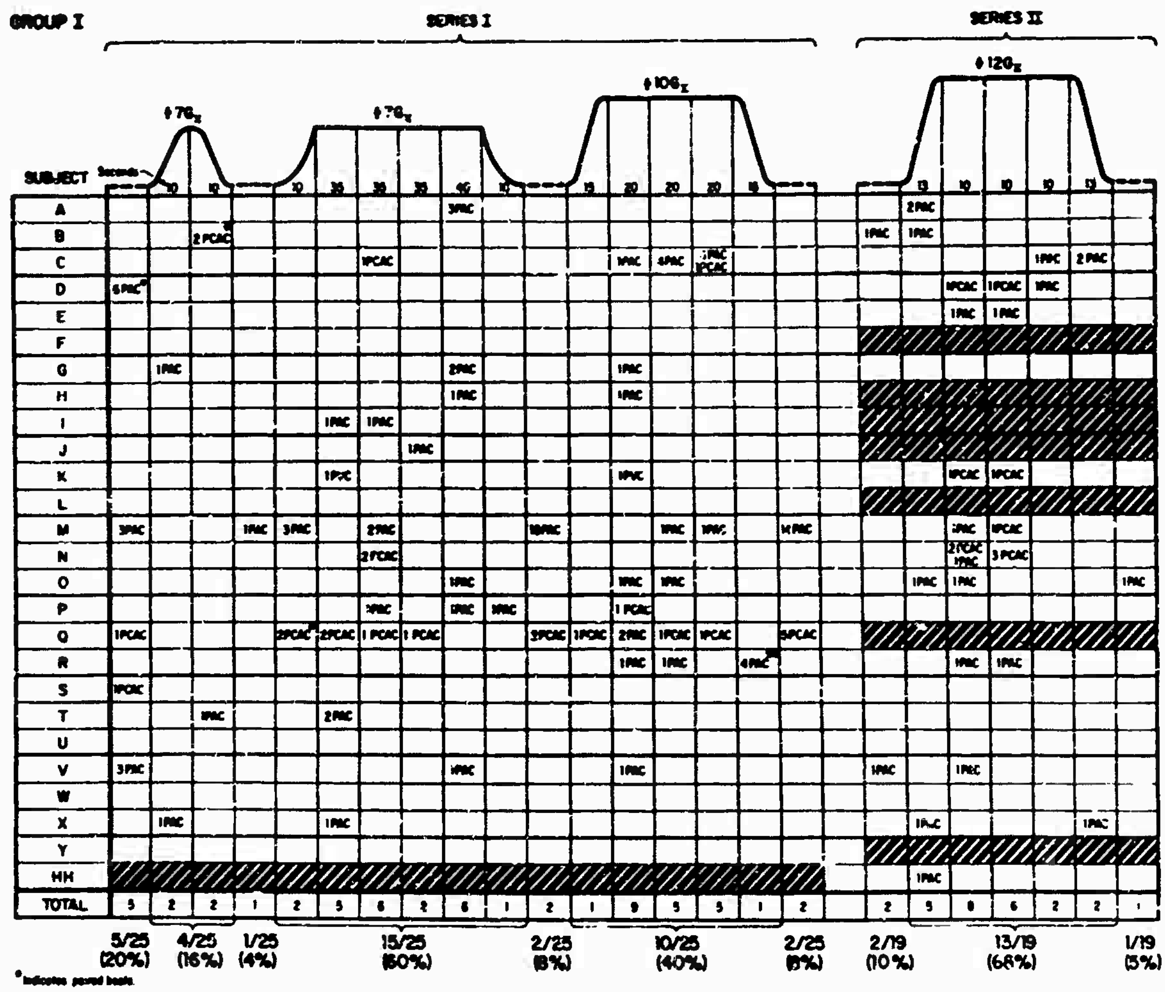

Fig. 1. Profiles indicating acceleration vector, levels attained and time are indicated at the top of the table. The response of each subject is seen in the table and indicated below is the incidence of ectopic beats during rest and acceleration periods.

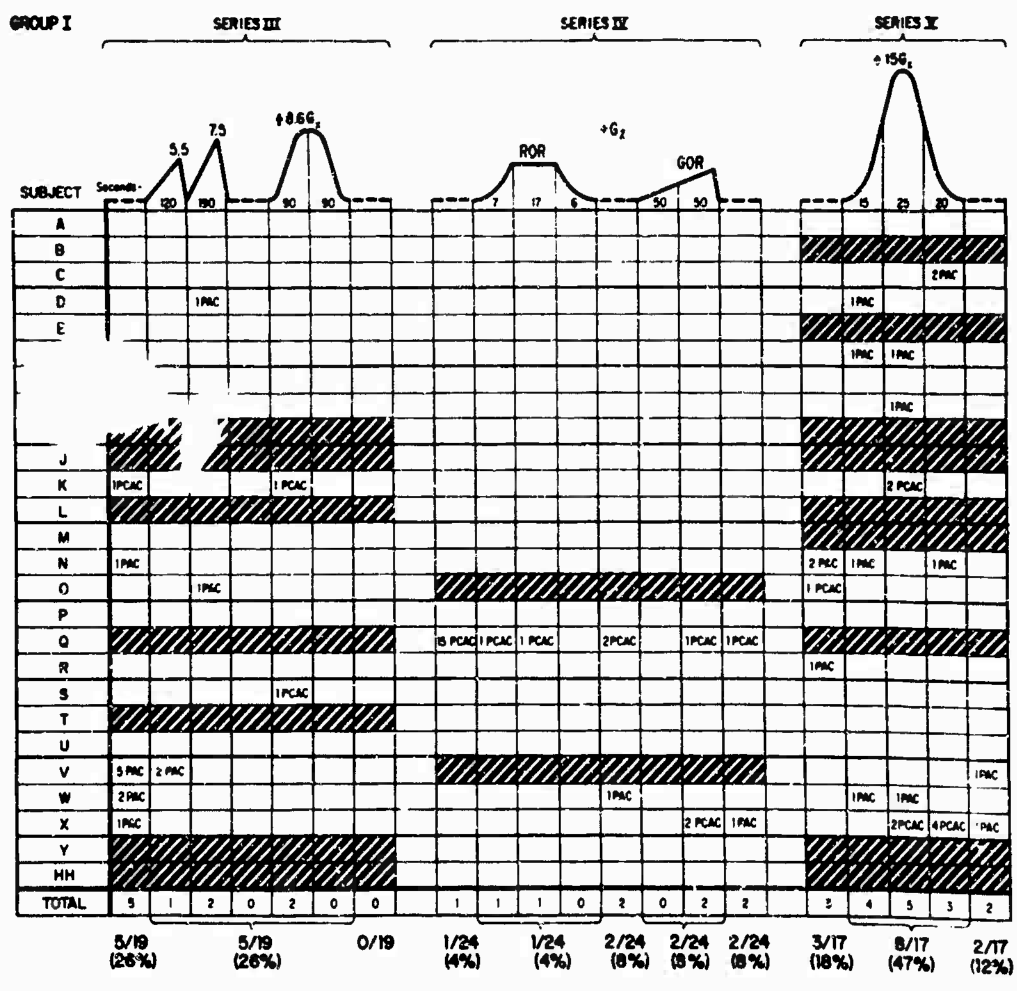

Fig. 2. Different profiles for the same subjects (Group 1) as shown in Figure 1.

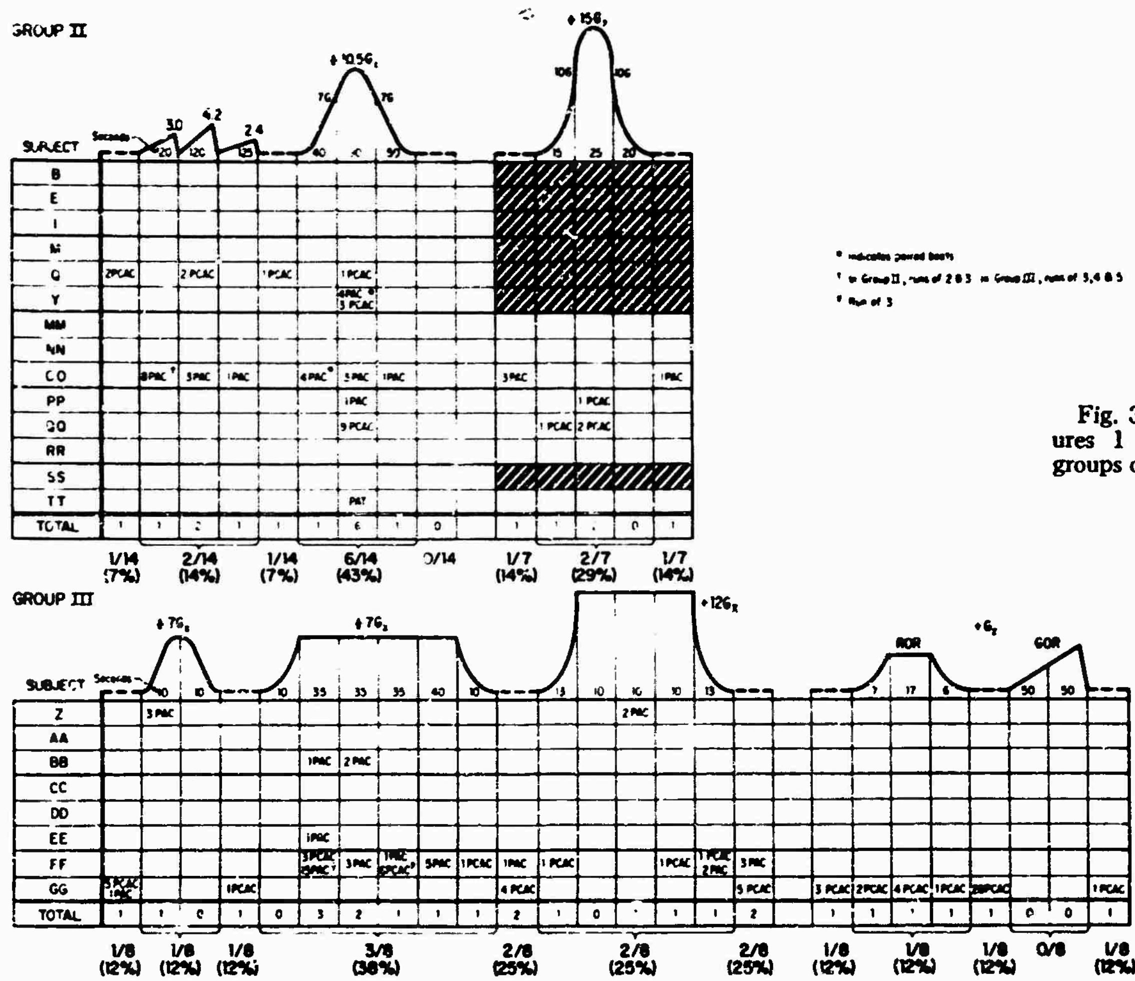

Fig. 3. Data presented as in Figures 1 and 2 but for two other groups of subjects (see text).

a plateau of 7 G, followed by a plateau of 12 G with short rest periods between each. On another day, each received a $+G_z$ evaluation with rapid onset and gradual onset runs as described for Series #4 of Group I.

For $+G_x$ exposure, the subject lay in a modified Mercury-type couch and was asked to perform a visually presented tracking task. For $+G_z$ exposure, the subject sat in a modified ejection seat and was required to turn off central and peripheral lights which were mounted on a bar in front of him and turned on by an observer in the control room.

In both configurations, the subject was monitored by television and he held a "dead man's" switch in one hand which, if released, would stop the centrifuge within a few seconds. The SAM human centrifuge has a 20 ft. radius arm with a freely swinging cab and is powered hydraulically. It can produce accelerations up to 50 G and onset rates of approximately 1 G/second. Hydraulic braking and friction braking are available, separately or together. The usual subject instrumentation consisted of an automated blood pressure cuff and microphone, two leads of ECG (biaxial and sternal) and a thermistor taped in or just below the nares to indicate respiration rate. Preamplified signals of these parameters were conducted through slip rings at the centrifuge hub and were recorded on a 8-channel Offner recorder in the control room.

RESULTS

Each record was carefully reviewed for arrhythmias and each atypical complex recorded, both as to its type and where in the acceleration profile it occurred. Although most records were available, some were lost or destroyed and these are indicated in Figures 1-3 by blacking out that profile for the subject. In any case, each profile could be presented separately for those subjects whose records were available without prejudicing the results. All records available were included.

Prematurities were classified as follows and examples of each are shown in Figure 4.

Premature Atrial Contractions (PAC)—Those complexes in which the initiating impulse clearly arose in the atria but not in the sino-atrial node.

Premature Ventricular Contractions (PVC)—This classification was restricted to those complexes where there was no doubt that ventricular excitation began below the A-V node.

Premature Contraction with Aberrant Conduction (PCAC)—These were complexes with an altered QRS pattern (indicating abnormal conduction pathways) but without clear evidence as to the locus of the initial excitation. Some atypical beats occurred successively in runs of two or more and these are indicated in the data. One subject, (TT) of Group II, developed paroxysmal atrial tachycardia (Figure 5) during the 10.5 $+G_x$ re-entry profile. This was preceded and followed by numerous premature beats and when re-exposed to this same profile on another day, PAT again resulted.

Figures 1 through 3, in addition to showing the acceleration-time profiles, record all arrhythmias for each subject during arbitrarily chosen segments of each profile. At the bottom of each graph is shown the incidence of arrhythmias during rest periods (+1 G) as

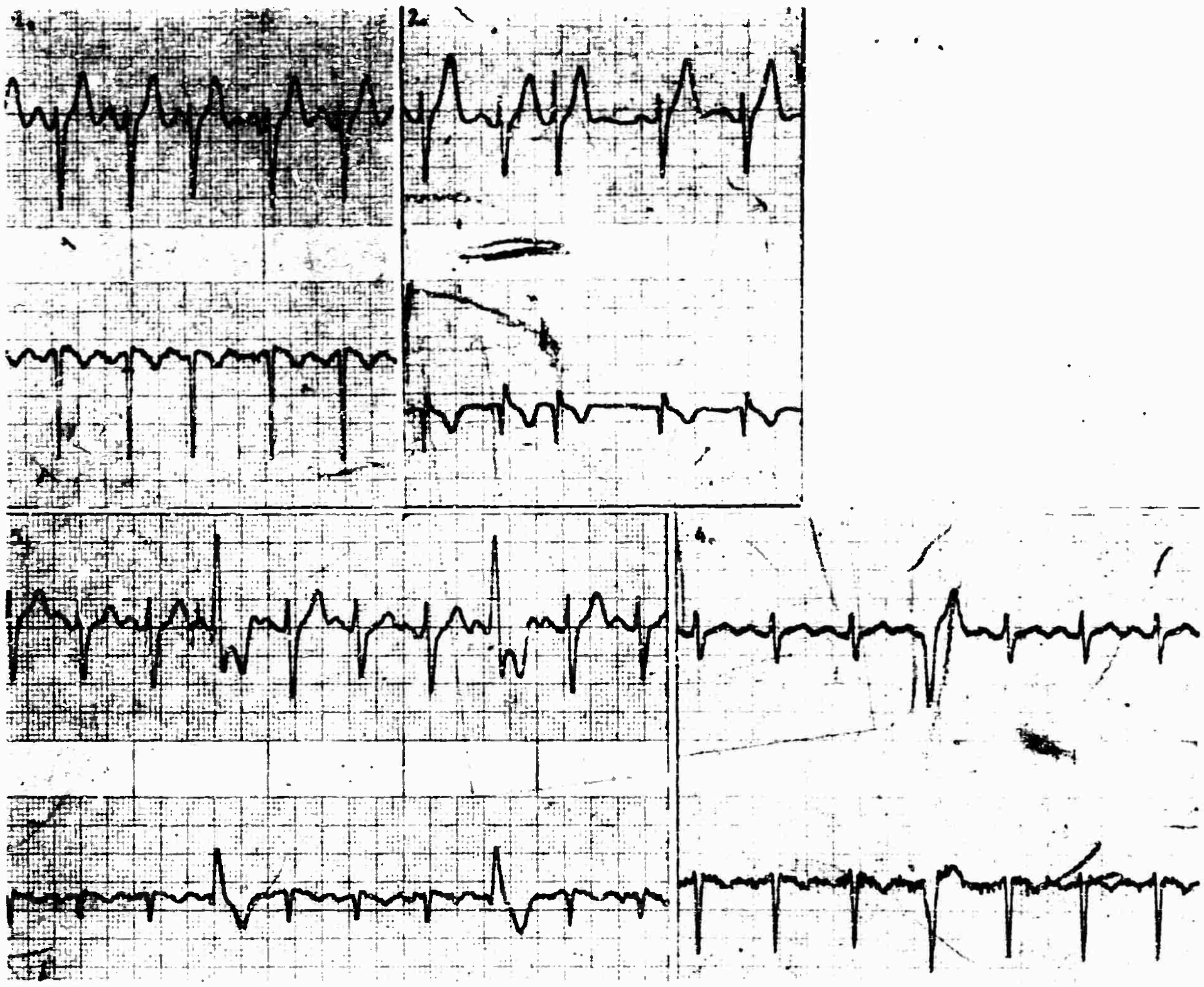

Fig. 4. Examples of ectopic beats seen in records.
1. Premature atrial contraction during 15 $+G_x$ profile.
2. Premature atrial contraction lying in $+G_x$ couch (1 G).
3. Premature contractions with aberrant conduction on 15 $+G_x$ profile.
4. Premature ventricular contraction during long 7 $+G_x$ plateau.

well as during increased acceleration both as the fraction of the number of men having records for that run and the percentage this represents.

The rest periods, although appearing shorter on this graph, were in fact longer in all cases than the acceleration periods preceding or following them. Therefore, if arrhythmias were not related to acceleration or a component thereof, we would expect to see more arrhythmias during these rest periods. That this is not the case is evident from the data. At the top of each figure, under the profile is shown the time of each segment in seconds.

Results for Group I, encompassing 26 subjects ranging in age from 27 to 33 years and with an average flying time of 2180 hours, are presented in Figures 1 and 2. All except Series #4 were $+G_x$. Series #4 was $+G_z$. Series #1, for this group, consisted of a short 7 G run, a 145 sec. 7 G run and a 60 sec. 10 G run. The short 7 G run produced premature beats in four individuals while five had prematurities before and after that run. Where only three subjects had arrhythmias before and after the long 7 G run, 15 of the 25 or 60 per cent showed them during the run. Ten of 25 or 40 per cent during the 10 G run had arrhythmias while only 2 of 25 or 8 per cent had them before or after.

Series #2, 12 G for 30 seconds, caused arrythmias in 13 of 19 subjects while 3 of 19 had them before and after.

Series #5 again shows increased arrhythmias with $+G_x$, 8 of 17 subjects.

Series #3 and Series #4 do not show increased incidence of arrythmias with acceleration. Series #4 is $+G_z$ acceleration and, in view of the large number of subjects and repeated runs (the single rapid onset run, ROR, on the graph represents from 5 to 10 or more runs for each individual), should have shown an increased number of arrhythmias if they were related to short term $+G_z$ acceleration.

Figure 3, representing Groups II and III, has the same arrangement and is self-explanatory. Composed as they are, of fewer subjects, the results are not so striking but similar. Members of Group II ranged in age from 31 to 35 years with an average flying time of 3390 hours while members of Group III ranged in age from 27 to 35 years with 1850 hours average flying time.

The immediate conclusion drawn from this data is that increased $+G_x$ acceleration is associated with premature beats in many individuals of these pilot groups. This increased incidence seems related to both the level of acceleration ($+8.6$ G_x, series #3 run as compared to the shorter series #5 $+15$ G_x run) and the duration of exposure (short $+7$ G run vs. long 7 G run). However, $+G_z$ acceleration, at least for short periods

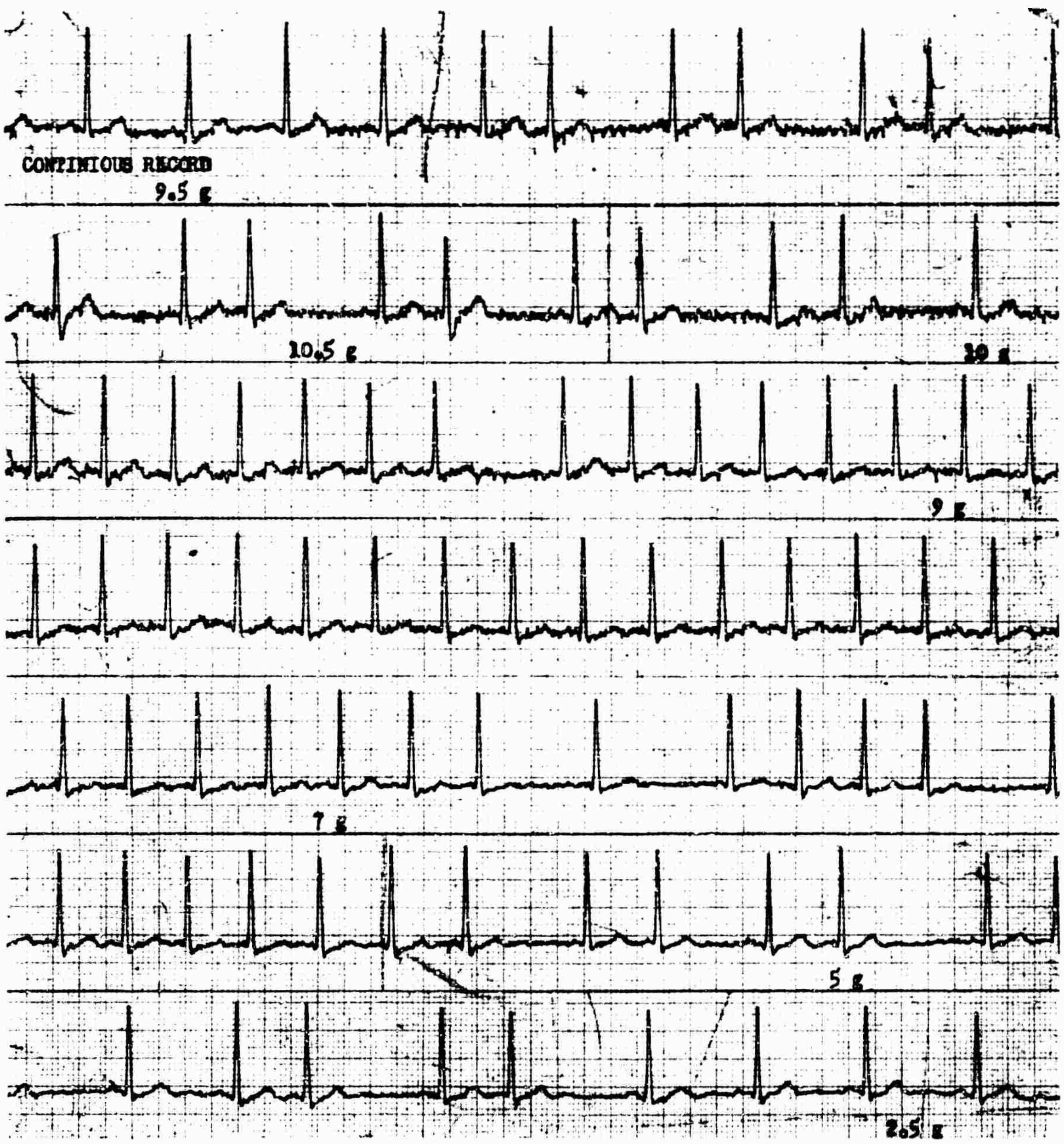

Fig. 5. Record extract of $+10.5$ G_x run of subject TT (Group II). Frequent atrial prematurities are seen in the 1st strip. The 6th, 8th, and 10th QRS complexes are examples of atrial prematurities occurring in a bigeminal or coupled fashion. In the 2nd strip, additional examples of atrial prematurities occurring in a bigeminal fashion, sometimes with aberrant conduction, are noted. In the 3rd strip, a run of atrial tachycardia is present which includes the first seven QRS complexes, this is followed by a pause, a normal beat and this is followed by another burst of atrial tachycardia. In strip 4, atrial tachycardia is present throughout the record. In strip 5, a burst of atrial tachycardia is terminated and followed by two normal complexes and then a succession of three atrial ectopic beats. In the 6th strip, atrial tachycardia is terminated after the 7th QRS complex. The 8th QRS complex is normal followed by an atrial prematurity. Examples of atrial prematurities in bigeminal fashion are seen in the remaining portion of the strip. In the 7th strip, atrial premature contractions are again noted.

(30 to 100 seconds), was not associated with rhythm changes in this study.

No arrhythmias, either at rest or with $+G_x$ or $+G_z$, were noted in 10 of the total of 42 pilots. Seventeen of the 42 had arrhythmias related to $+G_x$ acceleration. Two subjects (M and GG) may have had fewer arrhythmias with increased $+G_x$ acceleration than $+1G_x$ (lying in couch).

In one subject (TT of Group II), we recorded a potentially more serious arrhythmia, paroxysmal atrial tachycardia, with 10.5 $+G_x$ acceleration preceded by premature atrial contractions. This record is shown in Figure 5. Figure 6 shows the ECG during runs to 8.5 $+G_x$ and 10.5 $+G_x$ two days later, the first showing atrial premature beats and the second again with atrial tachycardia. A 45° head-down tilt five days after the initial run is shown in Figure 7 with a short burst of atrial tachycardia. There was no other evidence of cardiac disease in this subject.

DISCUSSION

Recent electronic developments, including personalized telemetry packages, small, light-weight recorders, certain computer technics and small, conveniently applied, relatively low-noise electrodes, have permitted physiologic monitoring of a variety of dynamic conditions and have revealed, for some, condition-related

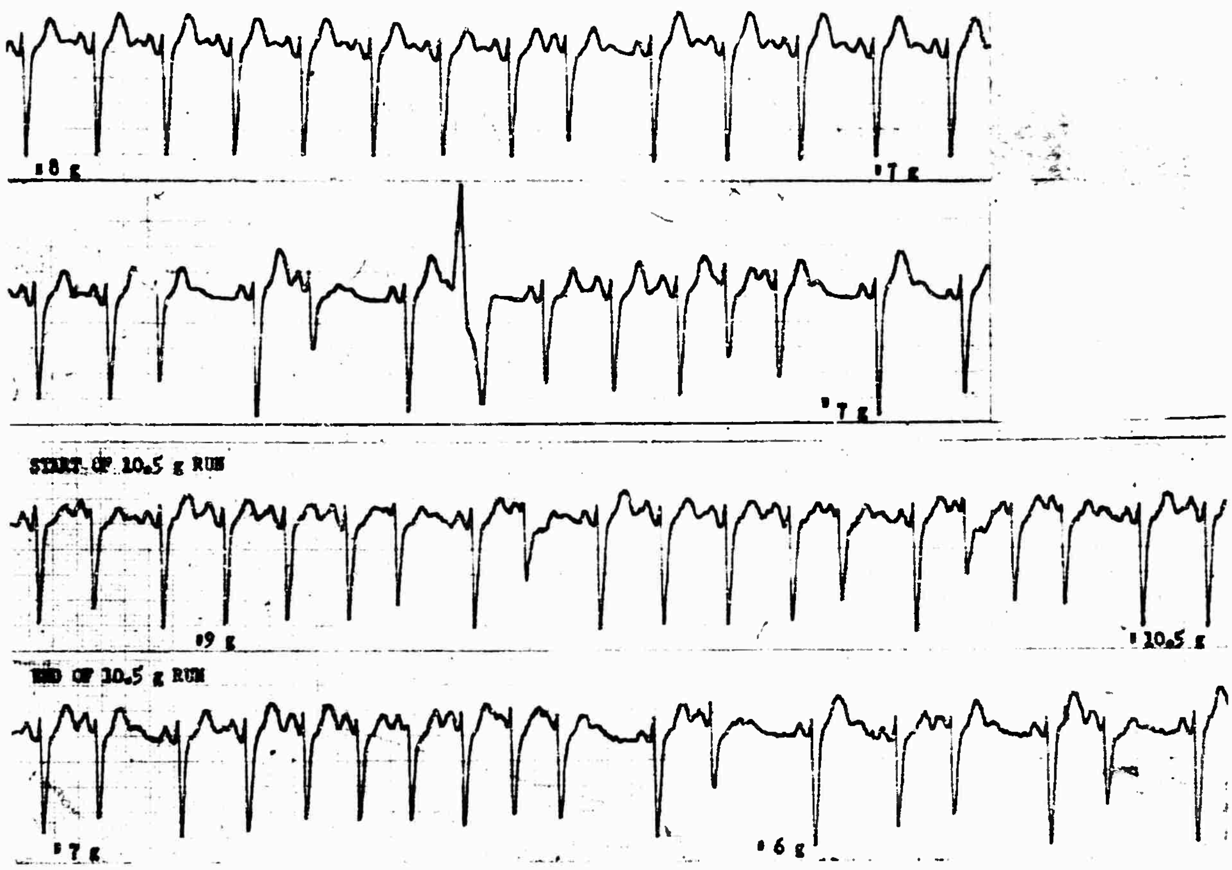

Fig. 6. This is the electrocardiogram of the same subject seen in Figure 5. In the top strip the 9th impulse is an artial premature contraction followed by a compensatory pause. In the second strip, the 3rd impulse is an atrial prematurity, the 5th impulse is an atrial prematurity with aberrant conduction, the 7th impulse is an atrial prematurity with aberrant ventricular conduction, the 11th and 12th impulses are atrial premature contractions, the remainder of the impulses are normal. In the 3rd strip the 2nd, 7th, 9th and 14th impulses represent atrial premature contractions. The 16th impulse is an atrial premature contraction followed by two more prematurities at a rapid rate constituting a short burst of atrial tachycardia. In the bottom strip the 2nd, 9th, 10th, 12th, 15th and 17th beats are examples of atrial ectopic impulses.

cardiac arrhythmias not previously suspected.

The striking effect of aircraft flight on heart rate and blood pressure[12] as well as concern for the effects of prolonged weightlessness necessitated the monitoring of certain parameters during space flight, including the electrocardiogram. Knowledge of the incidence of arrhythmias due to acceleration and not related to preceding weightlessness or other factors is desirable to preclude attribution of the arrhythmias to other causes.

$+G_z$ acceleration is known to raise blood pressure and heart rate.[5,6] Some investigators have reported that it causes arrhythmias;[2] others have commented on their absence.[3,11] Zuidema, et al.[15] studied five subjects during prolonged $+G_z$ (up to 115 sec.) and four of the five experienced arrhythmias, three having premature ventricular contractions, and one showing lower atrial or nodal premature beats and post run auricular fibrillation followed by bradycardia and sinus arrest.

Conflicting findings for $+G_x$ acceleration have also been reported. Duane, et al.[4] commented on the absence of arrhythmias with this vector. Bondurant and Finney[2] found fewer extra systoles with $+G_x$ than $+G_z$ while Barer, et al.[1] noted ectopic beats at $+G_x$ "plateau," one episode of bigeminal ventricular ectopic beats, and felt that this arrhythmia was at times related to respiration.

Our records show a definite increase in the incidence of ectopic beats with $+G_x$ (but not $+G_z$) acceleration, seemingly related to both the duration and degree of the force. Premature atrial, premature ventricular and premature beats of unknown origin but following aberrant conduction pathways were all found, as well as paroxysmal atrial tachycardia in one individual. The majority of the ectopic beats originated in the atria.

The factors which are known to cause ectopic beats are multiple and we can only speculate which of the factors initiate them during $+G_x$ acceleration. The supine position alone precipitates premature beats in some individuals[14] and fright or anxiety has been implicated by some investigators,[7] despite the associated tachycardia. Cardiac catheterization is not infrequently associated with arrhythmias, as are the more serious cardiac diseases such as coronary insufficiency, coronary occlusion, and myocarditis, particularly with diphtheria.

A variety of respiratory maneuvers, including breath holding, deep inspiration, and hyperventilation induce premature beats[8] and such maneuvers are frequently unconsciously performed during $+G_x$ acceleration. $+G_x$ acceleration results in lowering of the arterial blood oxygen saturation and probably localized areas of atelectasis,[10] either of which could stimulate premature beats.

Right atrial pressure increases during $+G_x$ acceleration[10] and Scherf, Scharf and Goklen have shown that distention of the atria causes fibrillation or flutter in the

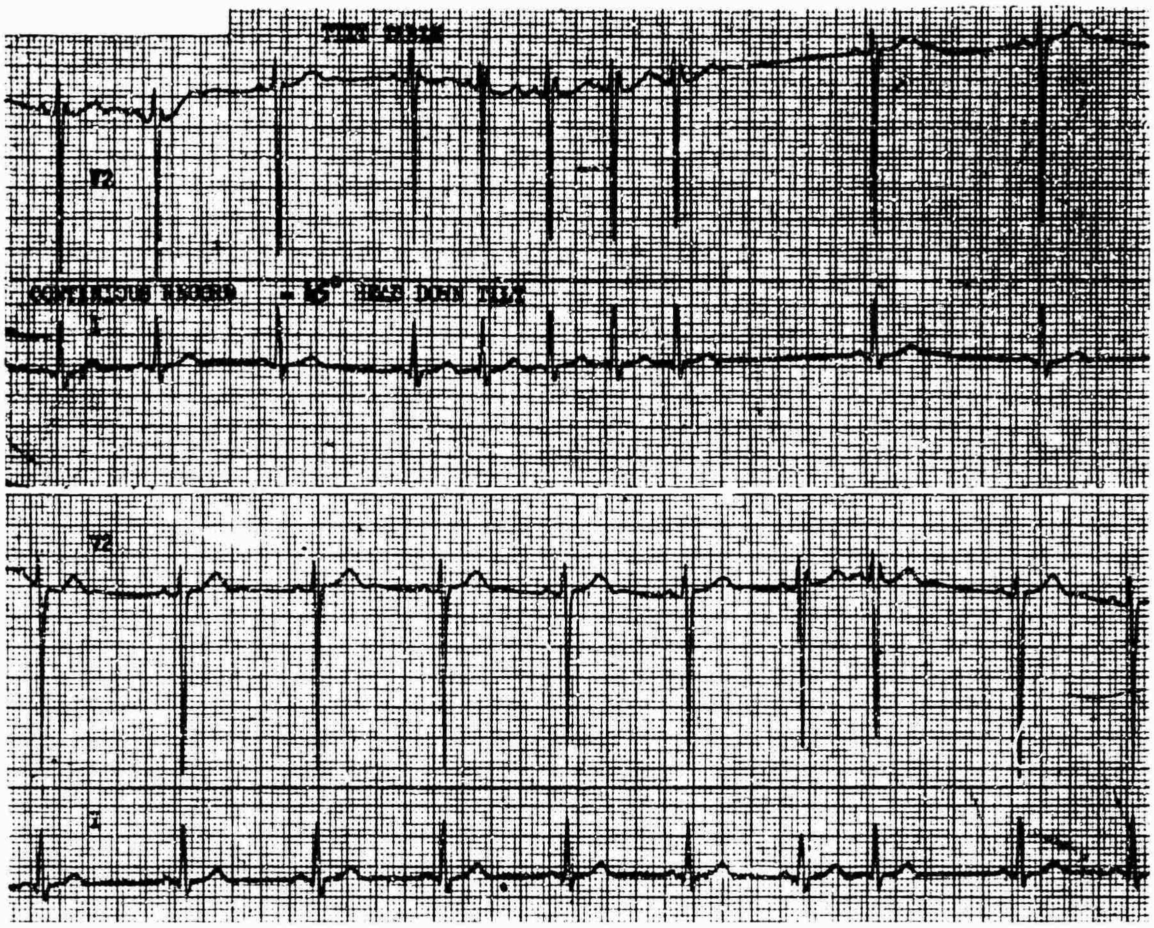

Fig. 7. This is the same subject seen in Figures 5 and 6 during a head-down tilt table procedure. Leads I and V_2 are recorded simultaneously. In lead I the 5th QRS cycle represents the onset of a short burst of atrial tachycardia of four successive beats followed by a pause and return to sinus rhythm. In the bottom strip a continuation of lead I shows that the 8th impulse is an atrial premature contraction.

aconitine treated dog heart.[13] Lamb and Roman[9] have reported the occurrance of cardiac arrhythmias, primarily atrial prematurities, during 45° head-down tilt which would also cause increased venous return to the heart. Distention of the right atrium as an explanation of the arrhythmias seems most inviting, considering the few arrhythmias seen with $+G_z$ acceleration which incorporates most of the other factors mentioned.

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